Design and Finite Element Analysis of Pre-pushing Double-cone Rotary Dredging Device in the Yellow River Irrigation Areas

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Abstract. In view of sediment deposition in the yellow river irrigation areas, a new pre-pushing double-cone rotary dredging device is described in detail in the paper, and the main structure is analyzed by finite element method. By hydraulic-driving technology and rotary stir-scour principle, the device can stir sediment deposition at the bottom of channel to turn into turbid muddy water, which can be washed away by water flow to complete dredging operation of irrigation channel.

Introduction

The Yellow River is the birthplace of our culture, as well as the main source of water in north China. Taking into account of water for production, living and ecology, reasonable use of water resources from Yellow River, including abundant storage for the withered and plentiful reserve of winter for the spring, is an important pioneering undertaking to promote harmonious development between man and nature and one that can tackle the uneven distribution of water resources in the middle and lower reaches of the Yellow River. There is high sediment concentration in the Yellow River, and low water velocity in irrigation areas can easily cause vast quantities of sediment deposition and the block of river channel. Therefore, it is a major measure to divert water from the Yellow River to irrigation areas [1].

In view of sediment siltation in the irrigation area, a new pre-pushing double-cone rotary dredging equipment is developed. The agitating device can stir silt at the bottom of channel into turbid muddy water to complete dredging operation. The equipment can help to enhance storage, discharge and supplie of channel water, improve water quality, speed up the construction of new rural areas and the integration of urban and countryside.

Stir-scour Dredging (SSD) Technology

Ordinary silt-dredging methods are similar, that is, river sediment is dug out and piled to both sides of the channel or settling basin, thus occupying more and more cultivated land, influencing ecology. Therefore, it is imminent to develop a new silt-removing and dredging technology. Stir-scour dredging method proposed in this paper can stir up sediment by self-developed pre-pushing double-cone rotary dredging device. The device can stir sediment in a predetermined way first, and then wash it away by water flow in a certain hydrological condition to complete dredging. The device can be fixed on a moving vehicle or ship, and it can be in a long-distance operation for hundreds of kilometers in the river bed with water depth of 0.5 to 3 meters. Dredging turntable can stir silt at the bottom of river bed into muddy water which can float again. Muddy water continues to flow downstream, and sediment deposition reduces to achieve dredging [2]. Compared with dredger, the equipment has the advantages of high efficiency and low cost, especially suitable for dredging in the Yellow River and corresponding irrigation areas.
For irrigation areas, the key to SSD technology is to solve siltation of river channel during irrigation. Research group has studied the mixing and settling process of river sediment by numerical simulation, which has laid theoretic foundation for stir-scour dredging.

Scheme design of Dredging Agitator

To accomplish sediment dredging flexibly and efficiently, it is vitally important to design a reasonable self-stirring device. The initial 4 design schemes are proposed and demonstrated comprehensively, and then establish three-dimensional model of the schemes on Solidworks platform. Taking into account many factors including convenient operation and maintenance, price ratio, reliability, stability and practicability, the structure of pre-push double-cone dredging turntable is determined finally.

Schematic of pre-push double-cone dredging turntable is shown in fig.1. The structure is mainly composed of three parts such as fixed main frame, swing arm and cone rotating device, among which cone rotating device consists of slewing bearings, hydraulic motor, precession device and turntable. In operation, install fixed main frame on moving vehicle or ship firstly, and then adjust working depth of precession device and turntable by hydraulic cylinder. Hydraulic motor drives slewing bearings to rotate precession device and turntable, and precession device can stir rigid silt into small pieces that can be crushed further by turntable. Therefore, silt will float. Open sluices in upper irrigation areas to increase water flow to remove sediment, thus achieving dredging of irrigation channel.

![Schematic of pre-push double-cone dredging turntable](image1)

Figure 1. Schematic of pre-push double-cone dredging turntable 1-Connecting pivot 2-Fixed main frame 3-Swing arm 4-Hydraulic cylinder 5-Slewing bearing 6-precession device 7-Turntable device

Structure Design of Pre-push Double-cone Dredging Turntable

Double-cone dredging turntable is made up of main plate, ring stiffener and eighteen cutting blades. Each blade is welded with stiffeners to enhance structural strength, avoiding stress concentration and blade bending. Design of dredging wheel takes full advantage of the rounded ability to distribute stress, with the minimum steel and the simplest structure to achieve required strength. Spiral blades are installed at the most front end of cone plate. Silt in the area where blades can not cover is crushed in advance to ensure dredging effect[^1].
Dredging wheel is connected with main frame by slewing bearing. Slewing bearing consists of two seating, with compact structure and light weight. Ball contacts with arc raceway on four points, withstanding axial force, radial force and overturning moment simultaneously, thus greatly improving reliability. And hollow slewing bearing can lighten weight of the equipment, save material and reduce water resistance, further enhancing dredging convenience[4].

At the most front end of the working device, hydraulic motor engages with slewing bearing directly to provide dredging power, with reliable transmission and small power loss. Hydraulic shunt can ensure that the two hydraulic motors have the same speed and rotational reliability.

**Finite Element Analysis of Working States**

ANSYS software is employed to carry out structural static analysis of the whole pre-pushing double-cone dredging turntable.

**Finite element simulation of cone turntable.** 3D model of cone turntable is created by SolidWorks, import it into ANSYS, which is shown in Fig. 2. Grid uses free division, finally obtaining 46178 nodes and 7636 elements, as is shown in Fig. 3.

![Figure 2. 3D model of cone turntable.](image1)

![Figure 3. Grid division of cone turntable.](image2)

Turntable bears gravity, water impact pressure and silt thrust. In calculation model, load can be handled as follows: for self-weight, preprocessing module of ANSYS inputs material density and gravity acceleration, and program will automatically enter the information of unit load factor into the total load according to unit type, real constant to calculate the solution. Strain distribution nephogram and stress distribution nephogram of the turntable are respectively shown in Fig.4 and Fig. 5, from which we can see that the maximum strain and stress are concentrated at the bottom where turntable touches silt. And the maximum strain and stress is 1.4mm and 236Mpa separately, meeting design requirements.

![Figure 4. Strain distribution nephogram of turntable.](image3)

![Figure 5. Stress distribution nephogram of turntable.](image4)
Finite element analysis of main arm 3D model of main arm is created by SolidWorks, and import it into ANSYS, which is shown in Fig. 6. Grid uses free division, finally obtaining 82331 nodes and 17576 elements, as is shown in Fig. 7.

Figure 6. 3D model of main frame on the working arm.  Figure 7. Mesh of main frame on the working arm.

Main frame of the working arm stands gravity, water impact pressure and silt thrust. In calculation model, load can be handled as follows: for self-weight, preprocessing module of ANSYS inputs material density and gravity acceleration, and program will automatically enter the information of unit load factor into the total load according to unit type, real constant to calculate the solution. Mass of front turntable, slewing bearing, hydraulic motor and main working frame is 75kg, 50kg, 50kg and 240kg respectively.

Figure 8. Strain distribution nephogram of main frame.  Figure 9. Stress distribution nephogram of main frame.

Strain distribution nephogram and stress distribution nephogram of main frame on the working arm are respectively shown in Fig.8 and Fig. 9, from which we can see that the maximum strain is concentrated at the front end, with the value of 0.8mm. And the maximum stress is concentrated on ear plate that is connected with hydraulic cylinder, with the value of 229Mpa, which meets design requirements.

Conclusions

The importance of sediment dredging in the Yellow River irrigation areas is introduced in detail in the paper. Based on hydraulic-driving technology and rotary stir-scour principle, a new pre-pushing double-cone rotary dredging device is developed, which can stir sediment deposition at the bottom of
channel to turn into muddy water. And then sediment can be washed away by water flow to complete dredging operation of irrigation channel. The equipment has many advantages including flexible installation, long working time, high reliability and good dredging effect. Finite element analysis of main structure has been carried out in the paper. Widespread application of the equipment helps to accelerate the construction of modern new countryside and promote the integration pace of urban and countryside.

References


